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Original communication

Metric method for sex determination based on the 12th thoracic vertebra in contemporary north-easterners in China

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ABSTRACT

Many studies have shown that discriminant function equations, used in the determination of sex from skeletons, are population specific. The aim of the present research was to develop discriminant function equations for sex determination using the 12th thoracic vertebra (T12) in a contemporary northeast Chinese sample and to investigate whether the differences of the T12 between males and females consist more in shape than in size. Thirty linear measurements were obtained from 141 three-dimensional reconstructed T12 models (78 males and 63 females), and then 112 ratios were calculated by using the thirty linear measurements. Of the 30 linear measurements, 28 were sexually dimorphic, and their univariate discriminant function equations predicted sex with 56.4–90.1% accuracies. Of the 112 ratios, 62 were sexually dimorphic, with accuracies ranging from 56.7% to 73.8%. Using stepwise method of discriminant function analysis, four variables predicted sex with 94.2% accuracy. It is concluded that the T12 vertebra of the north-easterners in China is useful for sex determination, and the size of the T12 vertebra contributes more than the shape in the differences of the T12 vertebra between males and females.

1. Introduction

A variety of bones have been studied metrically for drawing up a biological profile of an individual, such as the pelvis,[1,2] the skull,[3–14] the talus,[15–17] the calcaneus,[15,18–21] the humerus,[22–29] the femur,[30–40] and the patella.[41–43] In the field of forensic anthropology, drawing up the biological profile including determination of population affinity and estimation of sex, age and stature is vital, of which sex determination is the first essential step as it decreases the possible matches by 50%.[16] If the skeleton is complete and the investigator is well experienced, a good result can be achieved. Of course, it is also important to keep in mind that age-at-death and stature calculations are sex dependent.

Many bones are useful when it comes to sex determination.[16] For instance, the pelvis and the skull are reliable in sex determination and can predict sex with a nearly 100% accuracy.[2,44] But the presence of the pelvis and the skull can never be guaranteed in a forensic case. It is also clear that the reliability is not the only thing that matters when it comes to real forensic cases. When a skeletonised body is recovered, usually several parts are missing or are broken due to the effect of carnivores and environmental conditions. Furthermore, in mass disasters bones are usually commingled and broken in which situation identification of sex will be based on few components of the skeleton.[29] So it is necessary to develop metric methods on various kinds of bones, especially those without directly observable anatomical measurements of sex. Measurements of vertebrae,[45–47] the scapula,[48,49] the humerus,[22–29] the metacarpals of hand,[50] the femur,[30–40] the talus and the calcaneus[15–21] have been studied for sex determination.

However, sex determination method based on the 12th thoracic vertebra alone has been studied by Yu et al.[47] only. The fact that metric elements of human are population specific is widely acknowledged. Accounting for biological and statistical variation in the methods applied across populations and the ways in which such evidence is used in varying judicial systems is important because of the increasing amount of international forensic casework being done globally. Population variation or the perceived effect of such variation on the accuracy and reliability of methods is important as it may alter trial outcomes, and debates about the scientific basis for human variation are now making their way into international courtrooms.[51] The aim of the present study is to develop population-specific standards

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for sex determination based on the 12th thoracic vertebra in contemporary north-easterners in China, a population that has not been represented so far in the existing forensic anthropology population databases. According to previous studies by Yu et al.[47] and Zhang et al.,[52] metrical measurements are generally larger in males than in females. It is unclear whether this phenomenon is related to size or shape differences between male and female vertebrae. The present study is therefore designed to investigate whether sexual dimorphism observable on the 12th thoracic vertebra is related to shape or size differences.

2. Materials and methods

All the procedures for this study were approved by the ethics committee of Jilin University. The subjects used in this study are volunteers who had a need for computer tomography (CT) scan of the abdomen. The purpose of the present study was communicated to the patients before the commencement of CT scan and permission was obtained from all subjects. A total of 141 three-dimensional 12th thoracic vertebral models of northeast Chinese subjects (78 males and 63 females) was obtained from the Department of Radiology, China-Japan Union Hospital of Jilin University during the period of 2009.

CT imaging was performed using a helical CT scanner imaging machine (Light Speed 16, GE Medical System, General Electric Company, USA) (120 kVp; 320 mA; 512 × 512 matrix; slice thickness, 0.625 mm). The volunteers lay supine on the scanner. The scanning procedure was performed to acquire 0.625 mm CT slices from the plane of xiphoid process to the plane of anterior superior iliac spine. All images were retrieved on the CT workstation (advantage workstation 4.3, GE Medical System, General Electric Company, USA) and were reformatted with 3D reconstruction. The 12th thoracic vertebral models could be recognised by the 12th rib or by counting the lumbar vertebrae. The three-dimensional (3D) models of the 12th thoracic vertebrae could be rotated, cut, clipped, and measured.

None of the vertebrae used had any pathological condition. The mean age of the subjects was 46.88 years (range 18–79) for males and 47.48 years (range 20–76) for females. The mean height was 174.6 cm (165.3–182.4) and 160.7 cm (152.7–171.3) for males and females, respectively.

As many as 30 linear measurements as described in Table 1 and Fig. 1 were taken at the workstation by WBH, who had been trained for the job and has 1 year of experience in operating the workstation.

All the measurements were taken twice during two different periods with an interval of 4 weeks. The data of the first time and second time were analysed using one-way analysis of variance (ANOVA). Of all the 30 measurements, the differences between groups were not significant (*P* values ranged between 0.58 and 0.16, which means $P > 0.05$). So it was concluded that the measurements of the study were relatively of high precision, and they were valid. Then the mean values of all the 30 measurements of the two measurements were calculated and regarded as the final data.

Most measurements used in this study follow the definition of Yu et al. and are marked with asterix while the other measurements that we define are without asterix in Table 1. As many as 112 ratios were calculated as shown in Table 2. The data were analysed using SPSS version 13.0 (SPSS, Chicago, IL, USA). Univariate discriminant function analysis and stepwise discriminant function analysis were carried out respectively. A leave-one-out classification procedure was used to assess the validity of these functions.[16,47]

Table 1
Nomenclature for the measurements used in this study.

Symbol	Definition
(s*,i*,m)BDs	Central sagittal diameter of endplate on superior, inferior or median plane, distance from the most anterior edge of the endplate to the most concave point of the posterior edge of the endplate. (Body Diameter)
(s*,i*)BDsm	Lateral maximum sagittal diameter of endplate on superior or inferior plane, distance from the most anterior edge of the endplate to the most posterior edge of the endplate. (Body Diameter)
(s,i)VL	Sagittal length of the vertebra on superior or inferior plane, distance from the anterior edge of vertebral body to the posterior edge of vertebral spinal process at superior and inferior plane. (Vertebra length)
(s*,i*,m)BDc	Coronal diameter of endplate on superior, inferior or median plane, distance from the most left edge of the endplate to the most right edge of the endplate. (Body Diameter)
(r*,l*)PW	Width of vertebral pedicle on superior plane, distance between the two edges of the pedicle from a superior view. (Pedicle Width)
(r*,l*)MPL	Length of mammillary process and pedicle along the long axis of the pedicle on superior plane, distance from the most posterior edge of the endplate to the most posterior edge of the mammillary process. (Mammillary Process Length)
TDm*	Maximum distance between transverse processes from the most left edge of the transverse to the most right edge. (Transverse processes Distance)
(s*,i*)AD	Distance between superior or inferior articular process from the most left to the most right from a posterior view. (Articular processes Distance)
(ls*,rs*)APH	Height of superior, left or right articular process from the vertebral pedicles' superior border to the most superior edge of the superior articular process from a posterior view. (Articular process Height)
(li*,ri*)APH	Height of inferior, left or right articular process from the vertebral pedicles' inferior border to the most inferior edge of the inferior articular process from a posterior view. (Articular process Height)
(r*,l*)PH	Height of right or left vertebral pedicle, from the superior border to the inferior border. (Pedicle Height)
SPH	Height of spinal process from left view, from the superior border to the inferior border at the posterior 1/3 point along anterior–posterior axis. (Spinal process Height)
FDs*	Sagittal diameter of vertebral foramen on median plane. (Foramen Diameter)
FDc*	Coronal diameter of vertebral foramen on median plane. (Foramen Diameter)
SL*	Length of spinal process on median plane, from posterior border of the vertebral foramen to the most posterior edge of the spinal process. (Spinal process Length)
BHa*	Anterior height of vertebral body from left bisecting plane at the anterior part of the vertebral body at the point which can get the largest height. (Body Height)
BHm*	Median height of vertebral body from left bisecting plane at the median part of the vertebral body at the point which can get the smallest height. (Body Height)
BHp*	Posterior height of vertebral body from left bisecting plane at the posterior part of the vertebral body at the point which can get the largest height. (Body Height)

3. Results

Descriptive statistics of the linear measurements are presented in Table 3. All the dimensions differed significantly ($P < 0.05$) between sexes except for the sagittal diameters of vertebral foramen (FDs) and the height of the right inferior articular process (riAPH). Mean values of all the measurements are higher in males than in females.

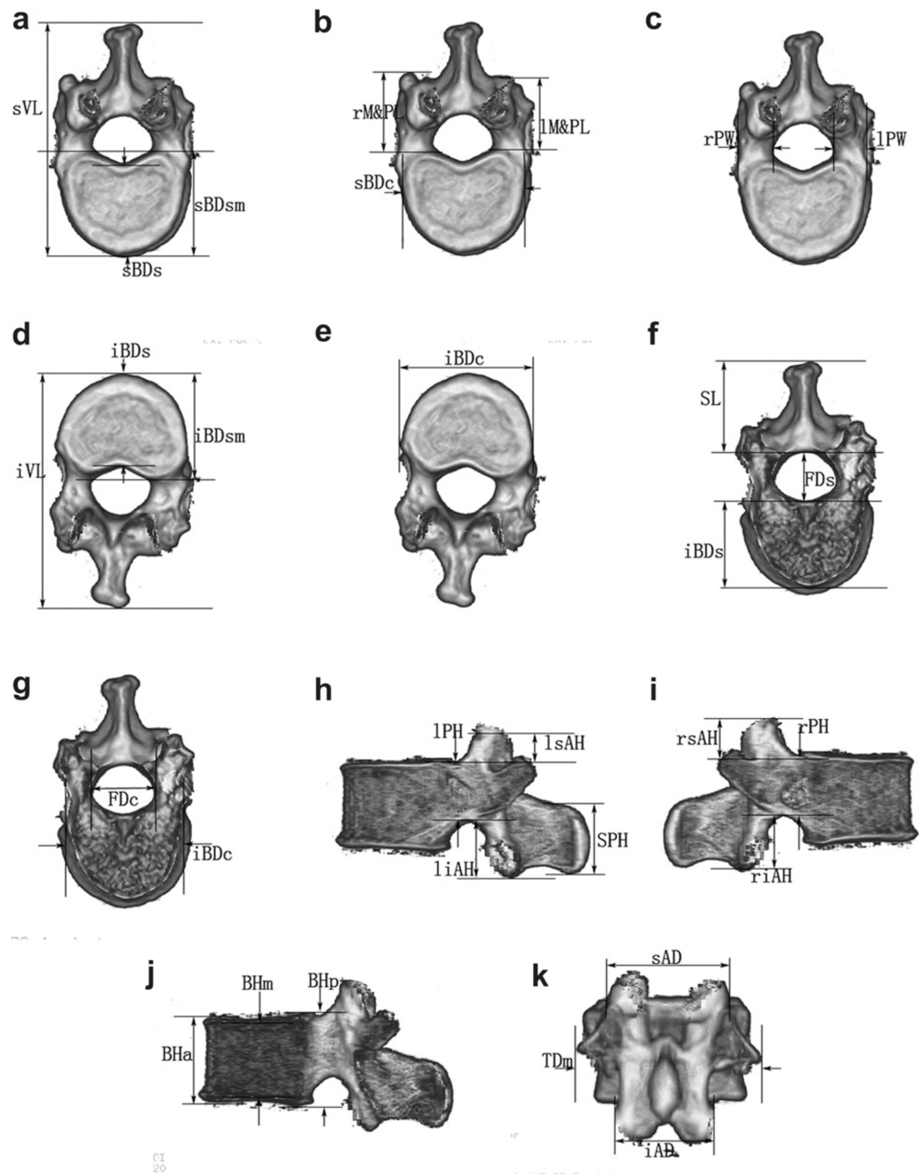

Fig. 1. Three-dimensional views of the 12th thoracic vertebra. The various measurements determined in the present study are indicated. (a)–(c) show the superior views of the vertebra; (d) and (e) show the inferior view; (f) and (g) show the inferior cross section view; (h) shows the left view; (i) shows the right view; (j) shows the right longitudinal section view; (k) shows the posterior view. Every measurement is marked on the view on which it was taken.

Table 4 shows the results of univariate discriminant function analysis of the 28 sexually dimorphic measurements. The accuracies of sex classification ranged from 56.4% to 90.1%. Measurements producing accuracies over 80% were: sBDs, sBDsm, sVL, sBDc, iBDs, iBDsm, iVL, iBDc, mBDs, mBDc and BHp. A special fact is that iVL had the highest accuracy of 90.1%.

Similar analysis was performed on the 112 ratios out of which 62 were found to be sexually dimorphic. The result is as shown in Table 2. The accuracies of correct sex classification ranged from 56.7% to 73.8%, which were lower than that of the linear measurements ($P < 0.01$).

Stepwise discriminant analysis was computed for which a function with four traits – three linear measurements (the superior maximum sagittal diameter of vertebral body endplate – sBDsm, the inferior length of the whole vertebra – iVL, the distance between superior articular processes – sAD) and one ratio (the ratio of anterior to posterior height of vertebral body – BHa/BHp), were obtained with accuracy of 94.2%:

$$\begin{aligned} \text{DFS} &= 3.322{*}\text{sBDsm} + 0.988{*}\text{iVL} + 1.14{*}\text{Sad} \\ &\quad - 10.818{*}\text{BHa/BHp} - 13.557\ (\text{section point} \\ &= -0.149). \end{aligned}$$

4. Discussion

The current study addresses standards for sex estimation of the 12th thoracic vertebral dimensions for contemporary northeasterners of China (a population that has not been represented so far in the existing databases). The 12th thoracic vertebra without directly observable anatomical measurements of sex shows a high

Table 2
The algorithm of all the ratios used in this study and their accuracies for predicting the sex of the 12th thoracic vertebrae.

Denominator Numerator	BHa	BHm	BHp	sBDs	sBDsm Accuracy	sVL	iBDsm	iVL	sBDc
sBDs	68.10	63.80	68.80	n	0.00	58.20	n	n	n
sBDsm	71.60	68.10	61.70	n	n	62.40	n	n	n
sVL	65.20	62.50	0.00	n	n	n	n	n	n
sBDc	73.80	66.70	62.40	n	n	n	n	n	n
rPW	0.00	0.00	0.00	n	n	n	n	n	0.00
lPW	0.00	0.00	0.00	n	n	n	n	n	64.70
rMPL	61.00	0.00	0.00	58.10	60.30	0.00	n	n	n
lMPL	62.70	0.00	0.00	56.70	61.20	0.00	n	n	n
iBDs	66.90	69.80	68.30	n	n	n	0.00	63.30	n
iBDsm	68.10	66.70	61.70	n	n	n	n	66.00	n
iVL	69.50	66.00	0.00	n	n	n	n	n	n
iBDc	68.80	69.50	63.80	n	n	n	n	n	n
TDm	0.00	0.00	0.00	n	n	n	n	n	57.40
sAD	57.70	0.00	0.00	n	n	n	n	n	61.30
iAD	0.00	0.00	0.00	n	n	n	n	n	61.00
lsAPH	0.00	0.00	0.00	n	n	n	n	n	n
liAPH	0.00	0.00	64.50	n	n	n	n	n	n
lPH	59.60	58.20	0.00	n	n	n	n	n	n
rsAPH	0.00	0.00	0.00	n	n	n	n	n	n
riAPH	0.00	0.00	60.30	n	n	n	n	n	n
rPH	66.70	59.60	0.00	n	n	n	n	n	n
SPH	63.00	61.50	0.00	n	n	n	n	n	n
mBDs	70.70	0.00	64.30	0.00	0.00	62.10	n	n	n
mBDc	67.40	0.00	0.00	n	n	n	n	n	0.00
FDs	0.00	65.00	61.70	66.70	65.20	60.30	n	n	n
FDc	58.90	64.50	0.00	n	n	n	n	n	58.90
SL	70.20	63.10	0.00	0.00	0.00	0.00	n	n	n
BHa	n	n	64.50	n	n	n	n	n	n
BHm	56.70	n	60.30	n	n	n	n	n	n
BHp	n	n	n	n	n	n	n	n	n

Accuracies are the results of cross-validation classification, those we don't use are marked "n", those whose $P > 0.05$ are marked 0.00.

Table 3
Sexual dimorphism in the linear dimensions of the 12th thoracic vertebra (mm).

Measurement	Male ($N = 78$)		Female ($N = 63$)		P
	Mean	SD	Mean	SD	
sBDs	33.06	2.00	28.88	1.74	<0.001
sBDsm	36.43	2.23	31.93	1.61	<0.001
sVL	77.84	4.63	70.84	3.30	<0.001
sBDc	44.76	2.94	39.65	2.30	<0.001
rPW	10.51	1.35	9.68	1.47	=0.001
lPW	10.58	1.29	9.97	1.34	=0.009
rMPL	25.57	2.28	23.47	1.99	<0.001
lMPL	25.58	2.01	23.55	2.21	<0.001
iBDs	33.79	2.04	29.45	1.67	<0.001
iBDsm	37.40	2.28	32.65	1.70	<0.001
iVL	79.54	4.35	71.58	2.86	<0.001
iBDc	47.81	3.18	42.05	2.62	<0.001
TDm	54.48	4.84	50.34	4.85	<0.001
sAD	37.92	2.44	35.19	2.52	<0.001
iAD	35.34	5.13	32.84	4.33	=0.008
lsAPH	9.40	1.76	8.58	1.84	=0.008
liAPH	20.35	2.32	19.46	2.25	=0.023
lPH	17.62	1.51	16.08	1.45	<0.001
rsAPH	9.41	1.88	8.70	1.66	=0.020
riAPH*	20.24	2.53	19.54	2.20	=0.084
rPH	17.64	1.46	15.79	1.25	<0.001
SPH	21.49	3.65	18.73	3.49	<0.001
mBDs	30.00	1.97	26.15	1.86	<0.001
mBDc	40.57	2.44	36.26	2.03	<0.001
FDs*	17.18	1.52	16.69	1.52	=0.055
FDc	22.81	2.49	21.00	1.84	<0.001
SL	28.68	3.73	25.48	2.38	<0.001
BHa	26.27	2.16	25.24	1.41	=0.001
BHm	23.29	1.63	21.93	1.28	<0.001
BHp	30.74	2.61	27.92	1.30	<0.001

(*$p > 0.05$).

Table 4
Unstandardized discriminant function equations and demarking points for predicting the sex of the 12th thoracic vertebra when using one measurement.

Variable	Unstandardized coefficient	Constant	Centroid (mean)	Demarking point	Accuracy
sBDs	5.29	−16.50	−0.11	3.10	84.40
sBDsm	5.06	−17.40	0.00	3.44	85.80
sVL	2.44	−18.26	0.00	7.47	81.60
sBDc	3.74	−15.89	0.00	4.25	83.70
rPW	7.12	−7.21	0.00	1.01	62.10
lPW	7.60	−7.84	0.00	1.03	56.40
rMPL	4.63	−11.41	0.00	2.46	68.40
lMPL	4.75	−11.71	0.00	2.46	73.90
iBDs	5.30	−16.88	0.00	3.18	86.30
iBDsm	4.90	−17.27	0.00	3.53	87.90
iVL	2.66	−20.22	0.00	7.60	90.10
iBDc	3.40	−15.36	0.00	4.52	83.00
TDm	2.07	−10.87	0.00	5.26	67.40
sAD	4.04	−14.83	0.00	3.67	68.60
iAD	2.09	−7.15	0.00	3.42	60.00
lsAPH	5.57	−5.03	0.00	0.90	57.60
liAPH	4.36	−8.70	0.00	1.99	60.30
lPH	6.74	−11.42	0.00	1.69	72.30
rsAPH	5.60	−5.09	0.00	0.91	57.20
rPH	7.29	−12.27	0.00	1.68	75.20
SPH	2.79	−5.67	0.00	2.03	68.90
mBDs	5.20	−14.70	0.00	2.83	83.60
mBDc	4.41	−17.05	0.00	3.86	81.60
FDc	4.50	−9.90	0.00	2.20	65.20
SL	3.13	−8.52	0.00	2.72	69.50
BHa	5.37	−13.86	0.00	2.58	66.70
BHm	6.73	−15.26	0.00	2.27	71.60
BHp	4.70	−13.87	0.00	2.95	83.70

Accuracies are the results of cross-validation classification.

discriminatory value of in sex determination. The result of this study concurred with the previous ones.[46,47]

The accuracy to predict sex correctly may reach as high as 94.2% when the bone is complete and the five measurements, including sBDsm, iVL, sAD, BHa and BHp, are measured. This fact made the 12th thoracic vertebra one of the most effective bones in sex determination. The present study and the study of Sheng-Bo Yu et al.[47] proved the 12th thoracic vertebra have an equal value in predicting sex with bones such as the humerus,[22–29] scapula,[48,49] the talus,[15–17] the femur,[30–40] and the patella.[41–43] The comparison with the previous work was displayed in Table 5.

There are lots of data on modern Chinese sex determination being published these years. Zhang studied bones such as femur[40] and tibia,[53] yielding different accuracy rates. Measurements of these bones are enriching the Chinese forensic anthropology databases. However, there are few data concerning the vertebrae for sex determination in China. Accounting for biological and statistical variation in the methods applied across populations and the ways in which such evidence is used in different judicial systems is vital for there being increasing amount of international forensic casework being done worldwide. Population variation or the perceived effect of such variation on the accuracy and reliability of methods is important because it may alter trial outcomes, and debates about the scientific basis for human variation are now making their way into international courtrooms.[51] Besides, vertebrae show great advantage in forensic cases because of their weight-bearing function and relative density, which makes them of great value in sex determination on difficult occasions. It was also Zhang who studied the lumbar vertebra on gender estimation on a Chinese sample.[52] On each vertebra, only 10 measurements were carried out. A series of formulae were obtained from each lumbar vertebra and five lumbar vertebra indexes; the discriminant rates are between 69.14% and 91.18%. The discriminant rate of the 1st lumbar vertebra is the highest which were 84.5%, and followed by the 2nd lumbar vertebra whose accuracy is 82.1%. The present study measured 30 linear items on the 12th thoracic vertebra, and calculated 112 ratios, which means a more detailed description of a vertebra than the study of Zhang. The discriminant function of the present study predicted sex more accurately than Zhang's study did.

Table 5
Comparison with the previous work.

Bones	Authors	Race	Accuracy		Publish year
			Univariable	Stepwise	
Hip bone	Bruzek J[2]	French and Portuguese	?	95%	2002
Crania	Kranioti EF[12]	Cretan	82%	88.2%	2008
Crania	Steyn M[6]	South African whites	86%	?	1998
Humerus	Rios Frutos L[28]	Guatemalan	95.5%	98.2%	2005
Humerus	Kranioti EF[29]	Cretan	89.9%	92.9%	2009
Femur	Iscan MY[30]	Chinese	94.9%	92.3%	1995
Femur	Mall G[34]	German	89.6%	91.7%	2000
Tibia	Xue R[53]	Chinese	95%	?	2009
Lumbar vertebra	Zhang J[52]	Chinese	84.5%	91.8%	2002
Patella	Dayal MR[42]	South African blacks	85%		2005
Patella	Akhlaghi M[43]	Iranian	92.9%		2010
Scapula	Ozer I[48]	East Anatolia	94.8%	?	2006
Calcaneus	Bidmos MA[21]	South African blacks	79%	?	2004
Talus	Bidmos MA[16]	South African whites	82%	88%	2003

"?"s means the data about the items are not available.

Table 6
Comparison of the measurements of the 12th vertebra between Chinese and Korean.[47]

Measurement	Chinese		Korean	
	Male	Female	Male	Female
sBDs	33.06	28.88	31.48	27.65
sBDsm	36.43	31.93	34.54	30.38
sVL	77.84	70.84	–	–
sBDc	44.76	39.65	44.37	38.81
rPW	10.51	9.68	10.96	9.33
lPW	10.58	9.97	11.17	9.19
rMPL	25.57	23.47	23.14	20.99
lMPL	25.58	23.55	23.03	21.25
iBDs	33.79	29.45	31.58	28.01
iBDsm	37.40	32.65	34.88	30.84
iVL	79.54	71.58	–	–
iBDc	47.81	42.05	47.20	40.98
TDm	54.48	50.34	53.26	48.29
sAD	37.92	35.19	–	–
iAD	35.34	32.84	27.35	26.18
lsAPH	9.40	8.58	5.49	4.55
liAPH	20.35	19.46	18.54	18.15
lPH	17.62	16.08	19.32	18.04
rsAPH	9.41	8.70	4.95	4.76
riAPH	20.24	19.54	18.75	18.06
rPH	17.64	15.79	19.86	18.36
SPH	21.49	18.73	–	–
mBDs	30.00	26.15	–	–
mBDc	40.57	36.26	–	–
FDs	17.18	16.69	13.91	13.57
FDc	22.81	21.00	19.36	18.71
SL	28.68	25.48	27.82	26.16
BHa	26.27	25.24	26.78	24.75
BHm	23.29	21.93	–	–
BHp	30.74	27.92	28.13	26.51

The present study concerned a similar problem with the study of Yu et al.[47] but in a different population. Some measurements used in the present study were different from the study of Yu et al.[47] as well as some were the same. Those listed in the study of Yu et al.[47] are marked with asterisk in Table 1 and those defined by ourselves have no marks. Measurements such as iVL and sVL defined by the present study do not exist in Yu et al.'s study. These two measurements were thought to be important characteristics about the wholeness of the vertebra by the present study. When it comes to the same traits, the measuring methods were different. For instance, Yu et al. measured iBDc in a way that is not clearly expressed and is ambiguous in his figure. So in the present study iBDc was set explicitly on a bisecting plane as Fig. 1(g) shows. However, it must be pointed out that the purpose of setting some traits on a bisecting plane is just to make it easier for us to understand. We do not require bisecting the vertebra when in real situation.

Generally speaking, Table 6 presents the dimensions of the 12th vertebra which were measured in the same way in the two studies, those of the Korean were smaller than those of the northeasterners in China. These differences between populations may be the results of environmental factors affecting bone growth as shown in Table 7. In Table 8 we could see the comparison of the

Table 7
Main environmental differences between northeast of China and South Korean.[47]

Items	Northeast of Chinese	Korean
Mean latitude	N43.5	N36.18
Topographic feature	Plain region	Mountainous and hilly region
Climate type	Continental monsoon climate	Oceanic monsoon climate

Table 8
Comparison of the results between Northeast of Chinese and Korean.[47]

Group	Northeast of Chinese	Korean
Mean height of the samples	Males: 174.6 cm (165.3–182.4) Females: 160.7 cm (152.7–171.3)	Males: 166.1 cm (159.0–178.0) Females: 156.4 cm (146.0–166.0)
Univariate discriminant function accuracy	56.4%–90.1%	62.7%–85.3%
Measurements producing accuracy over 80%	sBDs, sBDsm, sVL, sBDc, iBDs, iBDsm, iVL, iBDc, mBDs, mBDc and BHp	sBDc, sBDcm, iBDcm, and iBDc
Measurement with highest accuracy	iVL (90.4%)	sBDc (85.3%)
Stepwise discriminant function accuracy	94.2%	90.0%
Stepwise discriminant function	DFS = 3.322*sBDsm + 0.988*iVL + 1.14*sAD − 10.818*BHa/BHp − 13.557	DFS = 0.223*sBDc + 12.185*Hm/Hp + 0.213*lM&PL − 24.173

results between the two studies. The present study showed higher accuracy in both univariable and stepwise discriminant function analysis. The newly developed measurements in the present study such as iVL and sVL had a very good performance.

Compared with the study reported in the literature, the present study has arrived at an additional conclusion that the differences of the 12th thoracic vertebra between males and females consist more in size than in shape. The linear measurements which represent mainly the bones' size generally have higher accuracy than the ratios which represent mainly the bones' shape. The difference between the two is statistically significant ($P < 0.01$). Ratios were calculated by setting the body heights, sagittal and coronal diameters as the denominators, with a purpose of removing the effects of the differences in stature and weight between males and females. The result was that not even a ratio had accuracy over 75%, and the accuracies of ratios were statistically lower than those of linear measurements. So it could be deduced that stature and weight contribute greatly to the differences between males and females on the 12th thoracic vertebra. In other words, if a woman has a huge body, being tall and weighty, her 12th thoracic vertebra has a high chance to be predicted as male when using the method developed by the present study. To predict sex correctly, methods other than metric ones, such as biochemistry methods and chromosome analysis, should be developed. But this is not to deny the value of metric methods, because in certain situations, it is the metric methods that are the only effective ways.

The other disturbing problem is that readers could be assailed with doubts that the conclusions of the study may not be of practical significance when it comes to real bones because the present study was performed on the three-dimensional reconstructed models. However, as CT images were taken with 0.625-mm axial thickness of high resolution, the dimensional difference of the model from real bone is less than 1 mm. So the error could be ignored. The potential benefits of the CT scan method for sex determination are evident and include: (i) facilitation of the identification of unknown deceased individuals, (ii) avoidance of time-consuming maceration procedures, (iii) non-destructiveness of the procedure, and (iv) availability of large data sets of recent samples from various populations. Modern multi-slice CT is particularly suitable for the acquisition of volumetric data and allows for three-dimensional reconstruction of osseous structures.[54–65]

The 12th thoracic vertebra, as a bone, can also provide more biological information besides sex. Many studies have concerned age estimation,[66,67] stature estimation,[68,69] even race estimation from skeletons. So it is possible to predict the race, sex, stature and age from only the 12th thoracic vertebra, but a lot should be done before drawing up a complete biological profile from a piece of bone.

5. Conclusion

This study has shown that the 12th thoracic vertebra of northeasterners in China is sexually dimorphic. The bone is useful for sex determination, and the size of the 12th thoracic vertebra contributes more than the shape in the differences of the T12 between males and females.

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Conflict of interest
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